

Assimilation of Land Surface Skin Temperature Observations into the GEOS-5 Atmospheric Modeling and Assimilation System

Clara Draper

(with Rolf Reichle, Gabrielle De Lannoy, Qing Liu, Ben Scarino (NASA Langley), ...)

Global Modeling and Assimilation Office, NASA Goddard Space Flight Center

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Project outline

- ▶ Have introduced a land data assimilation system into the GEOS-5 AGCM/atmospheric data assimilation system
- ▶ Assimilate geostationary skin temperature (T_{skin}) observations into the land surface of the GEOS-5 AGCM/ADAS
 - ▶ Enhance assimilation of surface-sensitive atmospheric radiances
 - ▶ Improve land surface flux forecasts

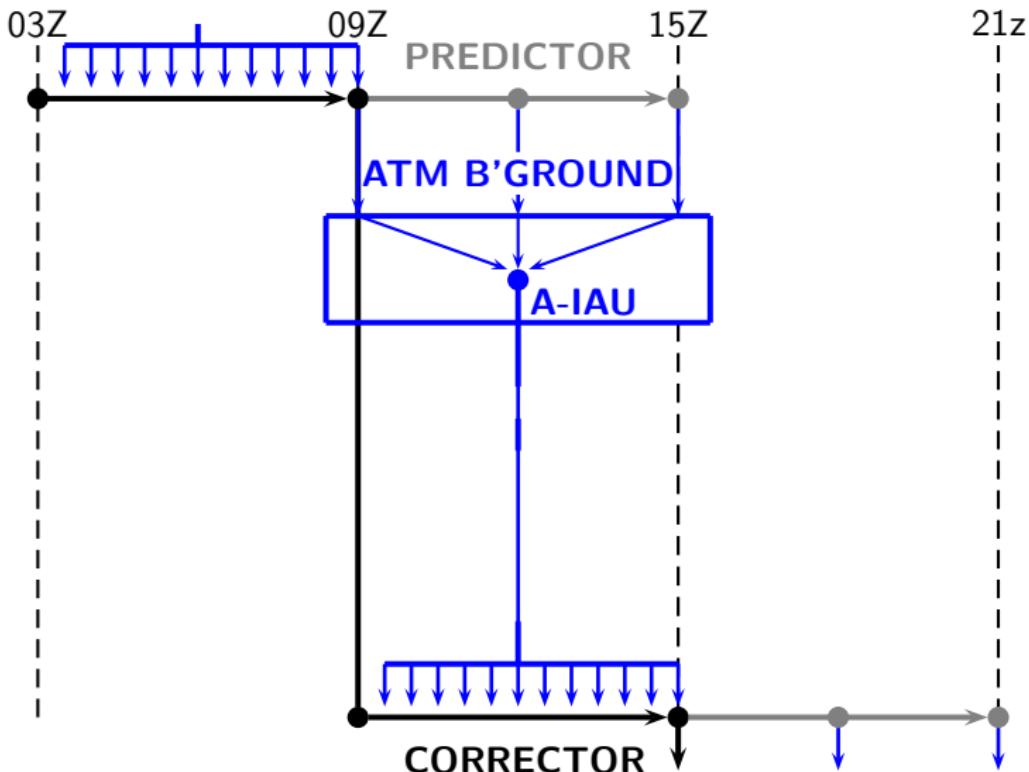
Presentation outline

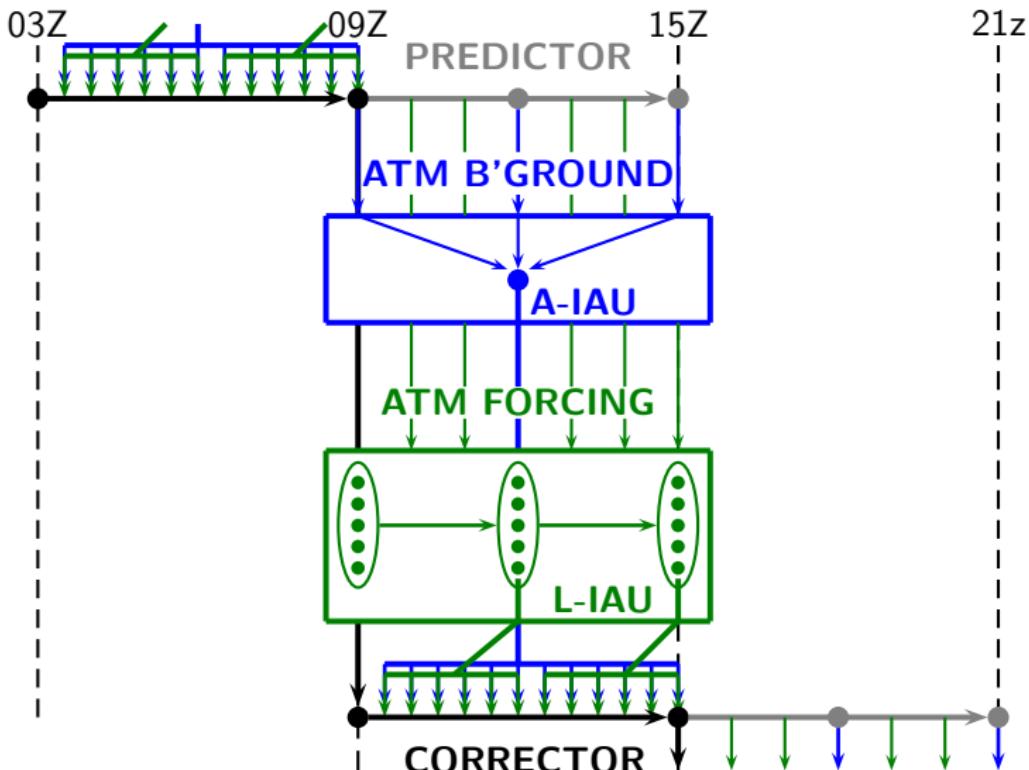
- ▶ Data/Methods:
 - ▶ 1. The Land/Atmosphere Data Assimilation System
 - ▶ 2. Modeled and remotely sensed T_{skin}
 - ▶ 3. Observation-forecast biases
- ▶ Assimilation results:
 - ▶ 4. Offline LDAS T_{skin} assimilation
 - ▶ 5. Coupled LA-DAS T_{skin} assimilation
- ▶ 6. Conclusions

1. The Land/Atmosphere Data Assimilation System

The GMAO Land-Atmosphere Data Assimilation (LA-DAS)

- ▶ ADAS: GEOS-5 AGCM/GSI (Rienecker et al, 2008)
 - ▶ Currently no land surface analysis, or assimilation of low level (2m) atmospheric temperature or humidity
- ▶ LDAS: Catchment (Koster et al, 2000) and GMAO Ensemble Kalman Filter-based LDAS (Reichle and Koster, 2005)
- ▶ LA-DAS:
 - ▶ LDAS weakly coupled to the ADAS
 - ▶ New strategy to address observation-forecast biases within constraints of atmospheric system

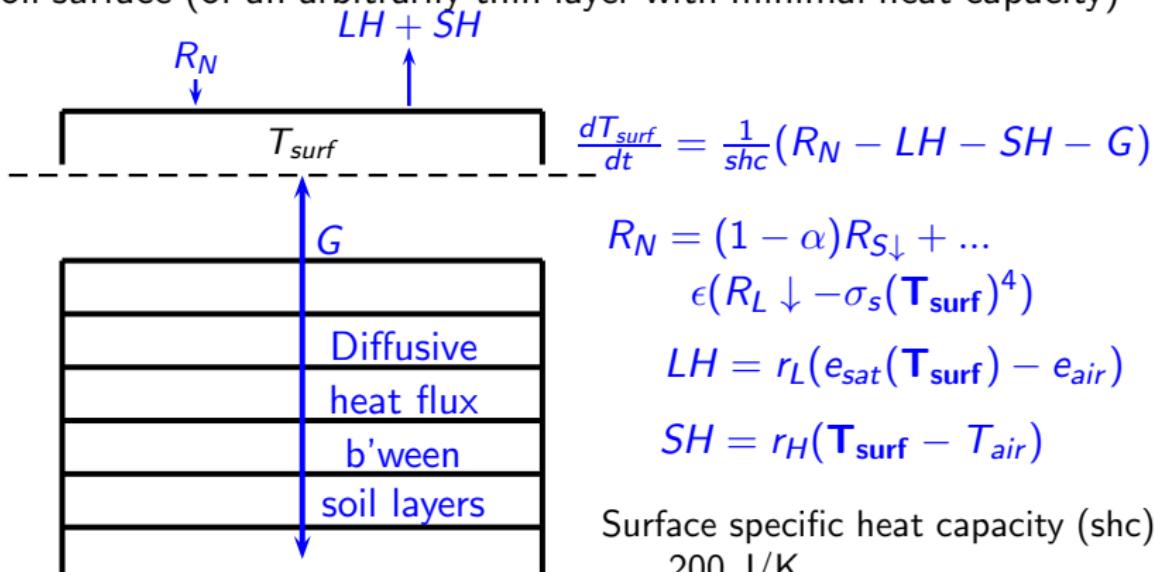




2. Modeled and remotely sensed T_{skin}

T_{surf} in GEOS-5 Catchment land surface model

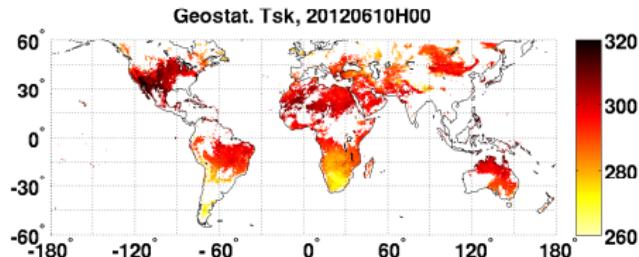
- Catchment T_{surf} is the average temperature of the canopy and soil surface (of an arbitrarily thin layer with minimal heat capacity)



Surface specific heat capacity (shc):
200 J/K
(70,000 J/K for broad-leaf green)

T_{skin} from geostationary satellites

- ▶ Near-real time geostationary T_{skin} data set from NASA Langley Research Center (LaRC)
- ▶ Similar accuracy to MODIS T_{skin}
- ▶ Reported 3-hourly (clear sky) at 0.25° resolution
 - ▶ GOES-E, GOES-W, Meteosat-9, MTSAT-2, FengYun-2E
- ▶ TIR/VIS observation of the clear-sky effective radiative temperature of the land surface (retrieved from clear-sky ($1 \times 1 \text{ km}^2$) pixels in each reported grid)



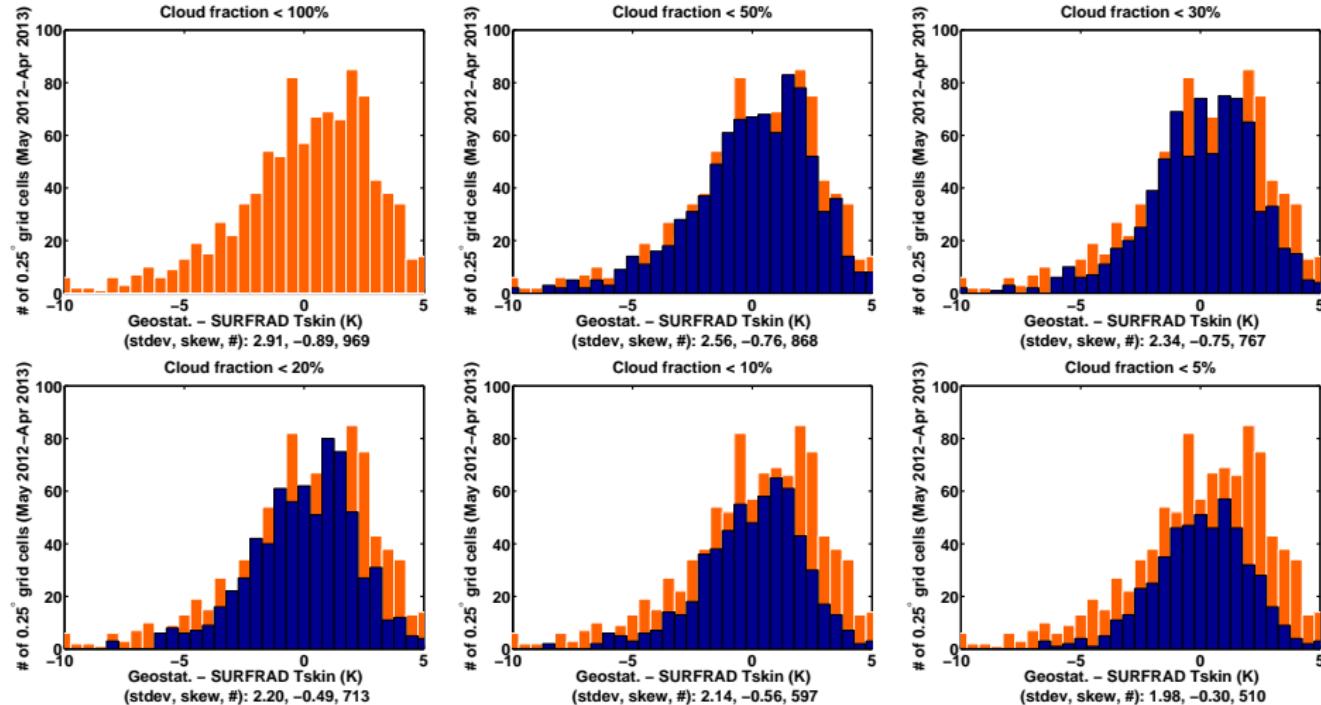
Scarino, B., Minnis, P., Palikonda, R., Reichle, R., Morstad, D., Yost, C., Shan, B., and Liu, Q. (2013), Retrieving surface skin temperature for NWP applications from global geostationary satellite data, *Rem. Sens.*

Evaluation of T_{skin}

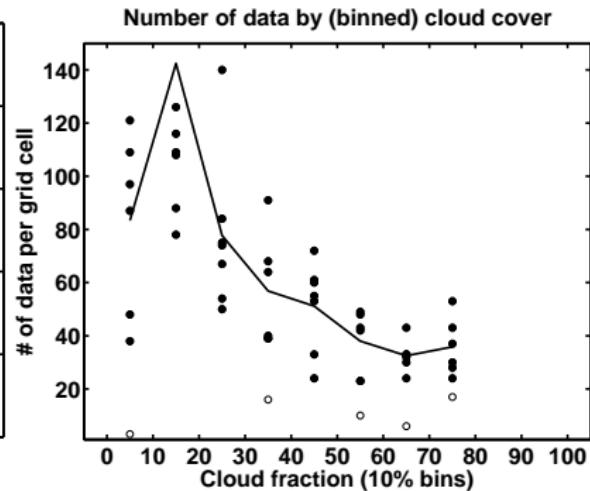
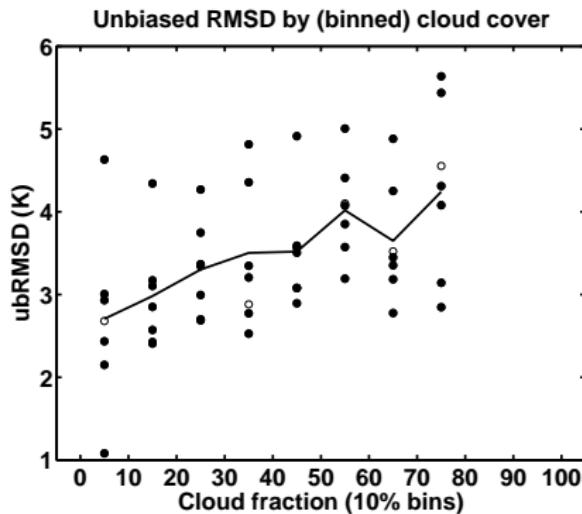
- ▶ GEOS-5/Geostat T_{skin} :
 - ▶ In situ T_{skin} observations: SURFRAD data (with monthly mean MODIS emissivity), hourly at 6 sites in the US
 - ▶ Remotely sensed observations: MODIS Terra T_{skin} data (MOD11C1), across Americas
- ▶ GEOS-5/Geostat T_{skin} :
 - ▶ Test impact of cloud fraction at SURFRAD sites



Geostat cloudiness threshold, Penn. State, PA (GOES-E)

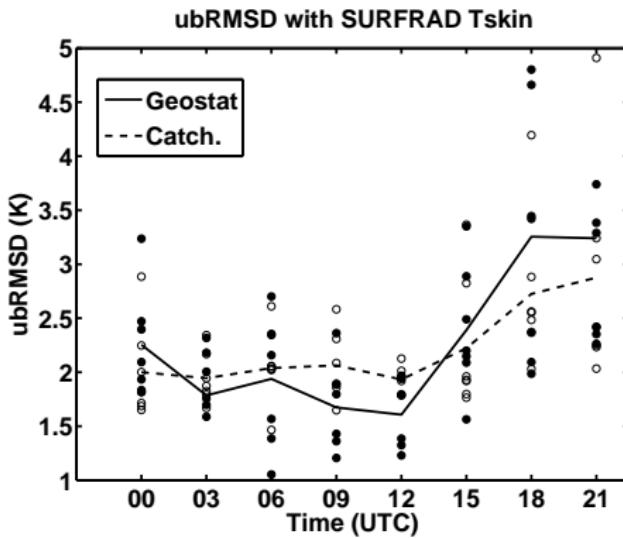


Geostat and SURFRAD T_{skin} , RMSD by cloud fraction (GOES-E/W)



- ▶ Set cloud fraction upper threshold for assimilation to 20%

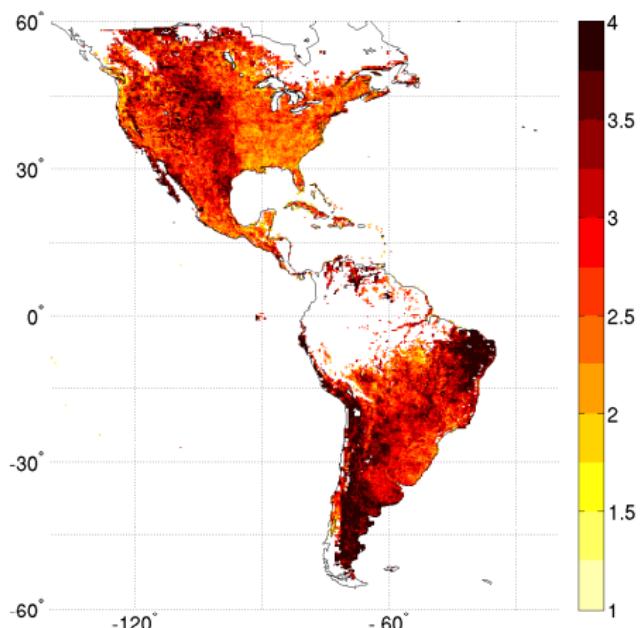
RMSD to SURFRAD T_{skin} (GOES-E/W)



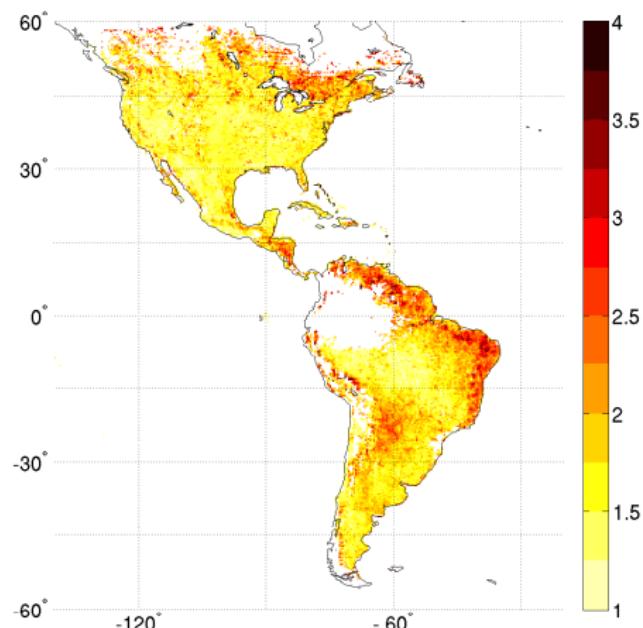
- ▶ Compared to SURFRAD, Catchment modeled and Geostat observed T_{skin} have similar skill
- ▶ Geostat (Catchment) has better fit during the night (day)

RMSD to MODIS T_{skin} (GOES-E/W)

Day (Terra dsc, 18 UTC)



Night (Terra asc, 06 UTC)

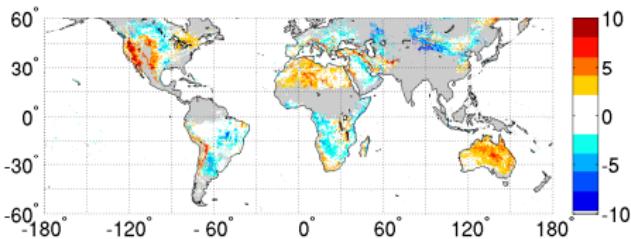


- ▶ Similar day/night skill as in comparison to SURFRAD T_{skin}

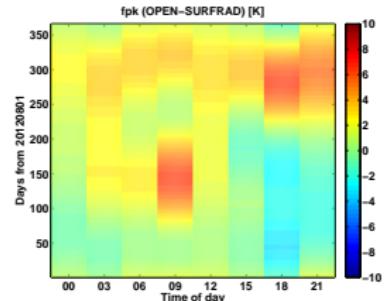
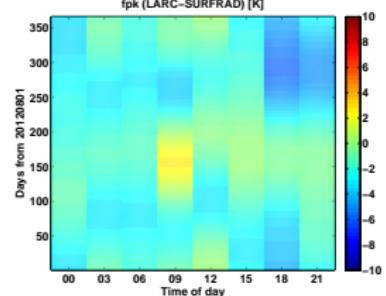
3. Observation-forecast biases

T_{skin} observation-forecast bias

Geostat. - GEOS-5 T_{skin} , mean Jul 2012, 00 UTC



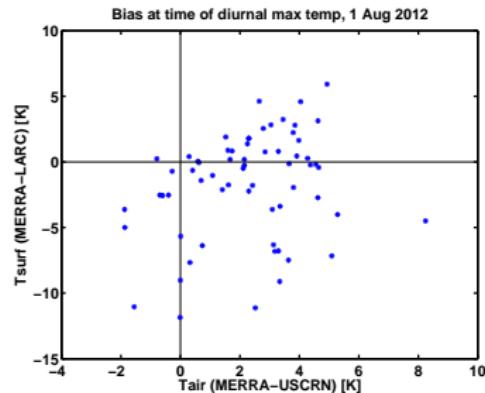
Comp. to SURFRAD T_{skin} , Fort Peck, MT



- ▶ Large forecast-observation biases, vary seasonally & diurnally
- ▶ Large biases ubiquitous in land DA
 - ▶ Over land few in situ obs. / highly heterogenous conditions
 - ▶ Cannot assign O-F bias to forecasts and/or observations (likely both)

Correct GEOS-5 T_{skin} towards the mean Geostat T_{skin} ?

- ▶ Ideally, want to correct GEOS-5 model T_{skin} biases
- ▶ Can we correct GEOS-5 T_{skin} towards the mean Geostat T_{skin} ?
 - ▶ Probably not: e.g., no relationship between the mean modeled - observed T for Tair (2m) and T_{skin} , at time of daily maximum T
- ▶ Would need to correct Geostat observed T_{skin} bias first (no verifying T_{skin} data set)



Observation-forecast bias in LDAS

- ▶ Standard in land DA (e.g., soil moisture DA) to assign O-F bias to observations within/prior to assimilation
 - ▶ At least ensures that the forecast and observations are not biased relative to each other
 - ▶ Allows assimilation to correct short-lived errors
- ▶ Long term: use indirect methods to estimate T_{skin} observation bias (Tair (2m)?)
- ▶ For now: use this approach for assimilating T_{skin} observations
 - ▶ Offline LDAS bias correction methods require long data record to estimate forecast and observed climatological statistics

Two stage observation bias and state estimation

- ▶ Similar to forecast bias correction of Dee and Todling [2000]
- ▶ State forecast and update:

$$x_{k,i}^- = f(x_{k-1,i}^+, q_{k,i})$$

$$x_{k,i}^+ = x_{k,i}^- + K_k(\tilde{y}_k^o - b_k^+ - H_k x_{k,i}^-)$$

(K is unchanged by inclusion of bias estimate)

- ▶ Bias forecast and update:

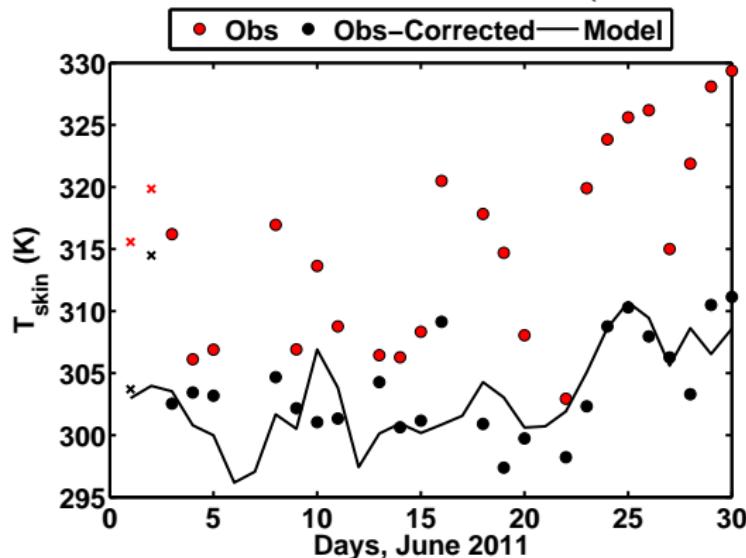
$$b_k^- = b_{k-1}^+$$

$$b_k^+ = b_k^- + L_k(\tilde{y}_k^o - b_k^- - \langle H_k x_k^- \rangle)$$

- ▶ Simplify by replacing L with empirical Λ , designed to update bias more aggressively when observations are available less frequently

Estimated bias correction example

18:00 UTC time series over June 2012, at (99.2W, 34.6N)



- ▶ Data only assimilated when have sufficiently recent observations for confident bias estimate (crosses not assimilated)

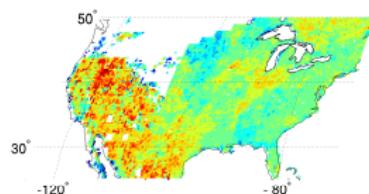
4. Results: offline LDAS

LDAS experiments

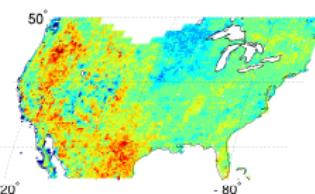
- ▶ LDAS: Assimilate GOES-E and GOES-W T_{skin} over North America into Catchment model forced with MERRA
 - ▶ Assimilate 3-hourly, for one year from May 2012
 - ▶ Estimate observation bias using 2 stage bias and state estimation separately at each time of day
- ▶ CNTRL: control run is openloop (no assimilation) ensemble mean

Observation bias correction output, at 00 UTC

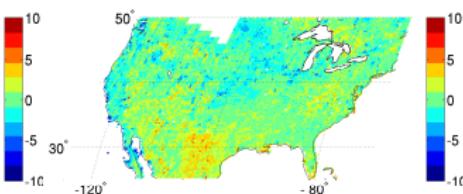
LDAS estimated bias (K)



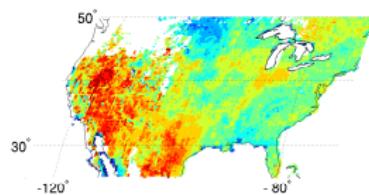
LDAS estimated bias (K)



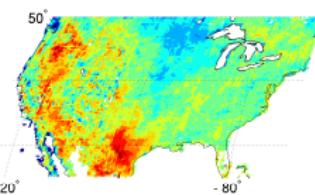
LDAS estimated bias (K)



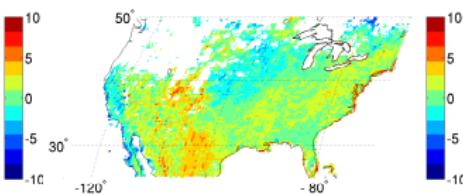
Mean 31-day obs-model (K)



Mean 31-day obs-model (K)



Mean 31-day obs-model (K)

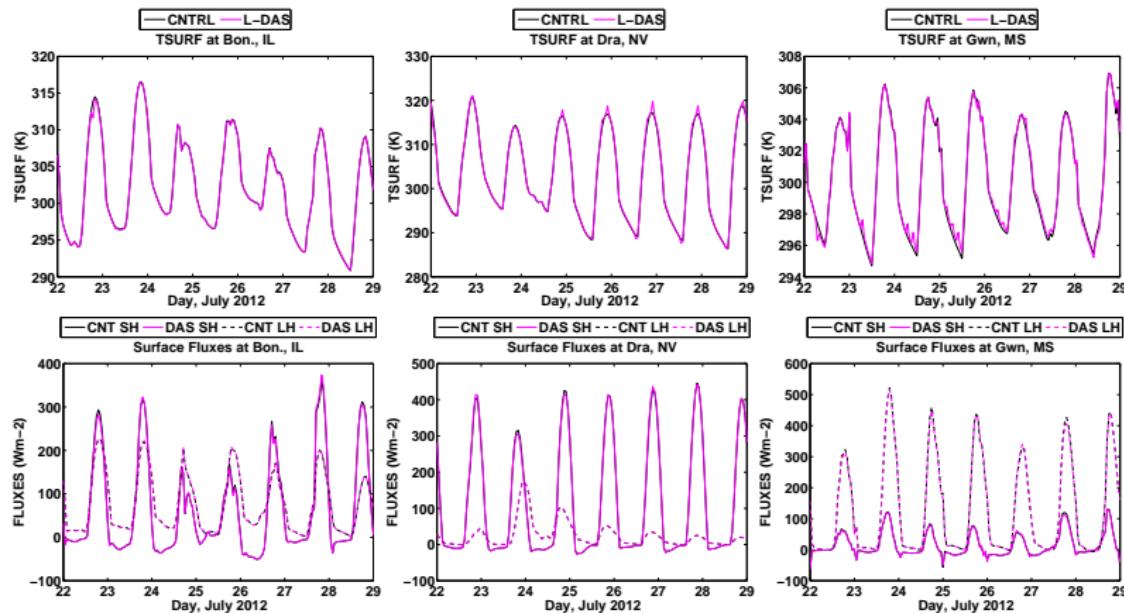


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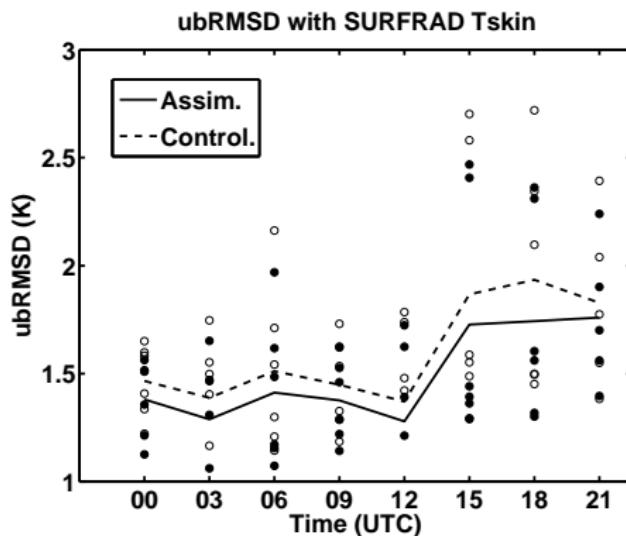
20121201

Assimilation results at SURFRAD sites



- ▶ Plots are hourly instantaneous values
- ▶ T_{skin} has almost no memory (v. low specific heat capacity) , updates do not persist, do not impact fluxes

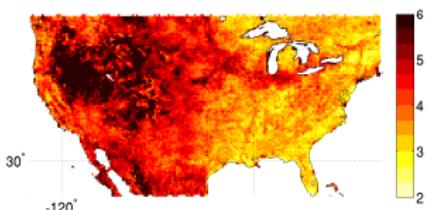
Comparison to SURFRAD T_{skin}



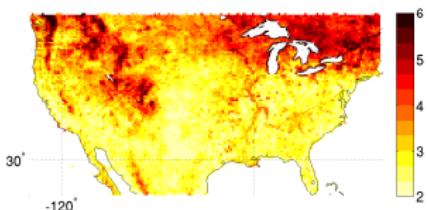
- ▶ Consistent small (0.1K) improvements from the assimilation
- ▶ Statistics calculated at time of analysis only

Comparison to MODIS T_{skin}

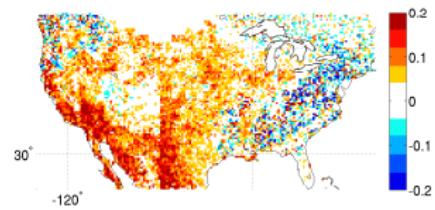
CNTRL ubRMSD (K), 18 UTC



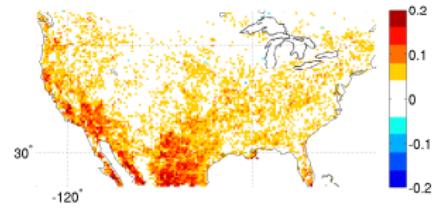
CNTRL ubRMSD (K), 06 UTC



Improvement in ubRMSD (K) from assim., 18 UTC



Improvement in ubRMSD (K) from assim., 06 UTC

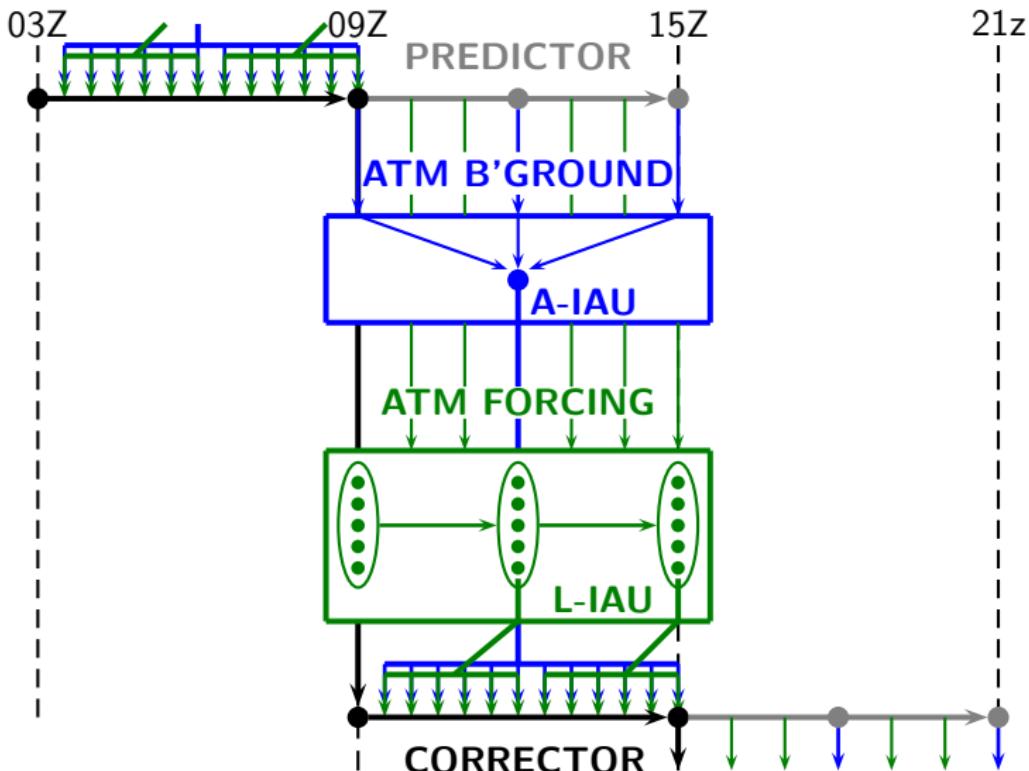


- ▶ Consistent small (0.1K) improvements from the assimilation
- ▶ Statistics calculated at all times

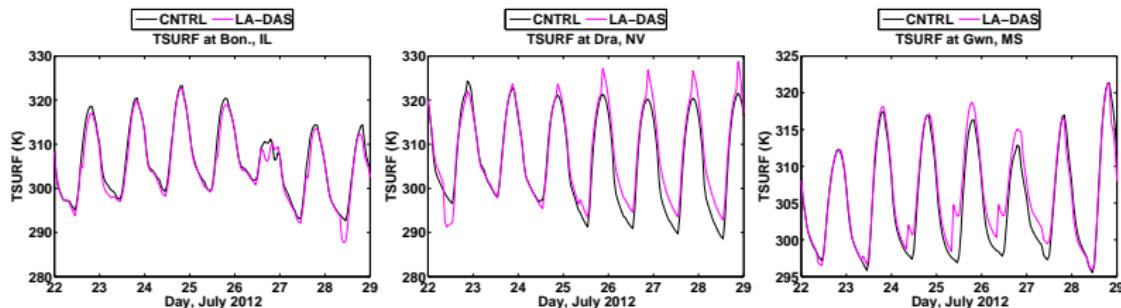
5. Results: coupled LA-DAS

LA-DAS experiments

- ▶ LA-DAS: Assimilate GOES-E and GOES-W, for one month from 14 July 2012 over Americas
 - ▶ Same AGCM, GSI set up, assimilated (atmospheric) observations classes as GMAO FP-IT system
(except resolution: $0.625^\circ \times 0.5^\circ$ (reg. grid), 72 vert. levels)
 - ▶ Nb: no low-level (2m) atmospheric temperature/humidity observations, or surface analysis
- ▶ CNTRL: control run, as above but without LDAS component

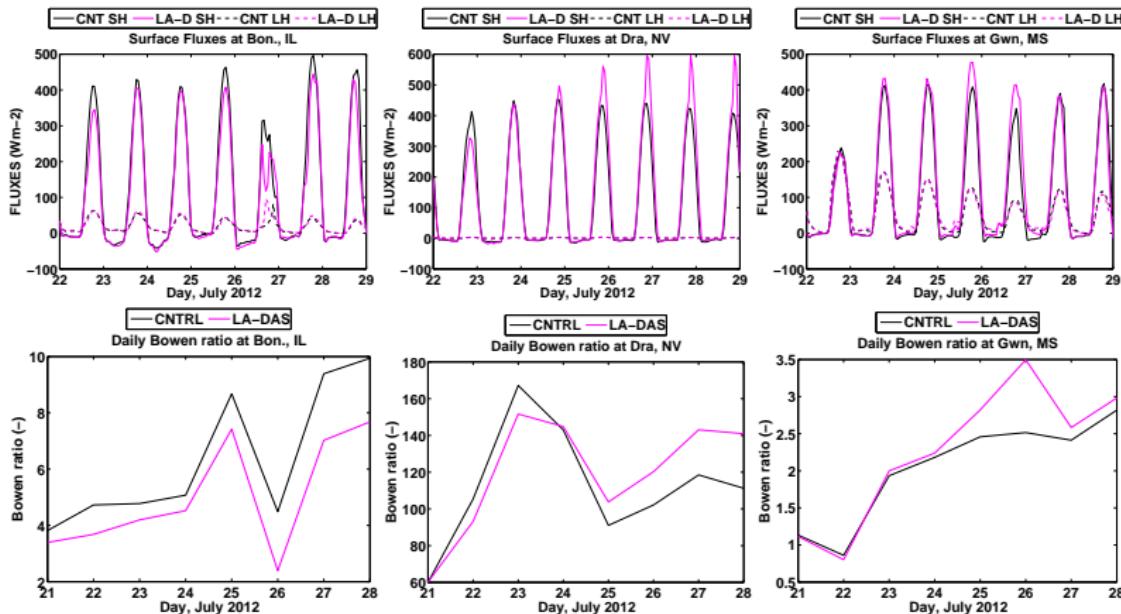


Assimilation results at SURFRAD sites: T_{skin}



- ▶ Plots are hourly mean values from the predictor segment
- ▶ T_{skin} has some memory of previous updates (c.f. offline LDAS)

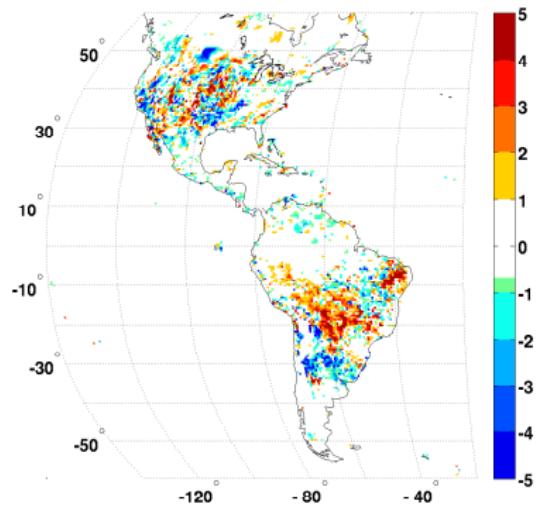
Assimilation results at SURFRAD sites: fluxes



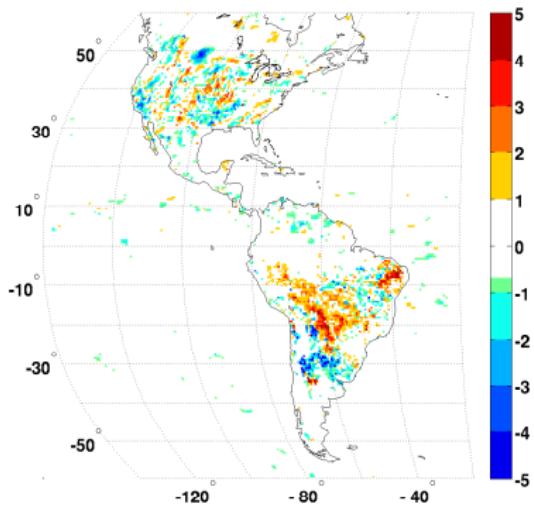
- ▶ Plots are hourly mean values from the predictor segment
- ▶ T_{skin} updates impact fluxes and Bowen ratio (c.f. offline LDAS)

LA-DAS minus CNTRL, 20120720H21

TSURF



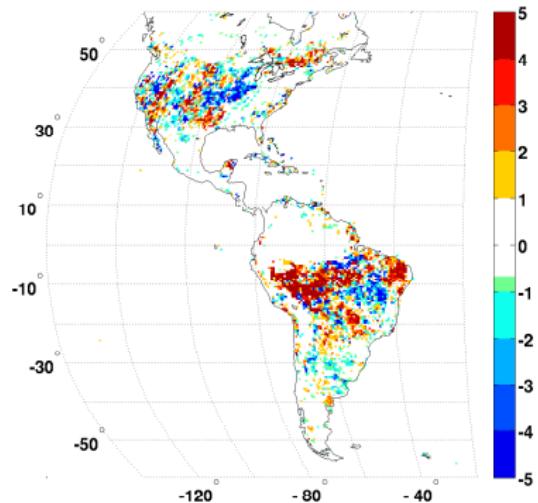
T2M



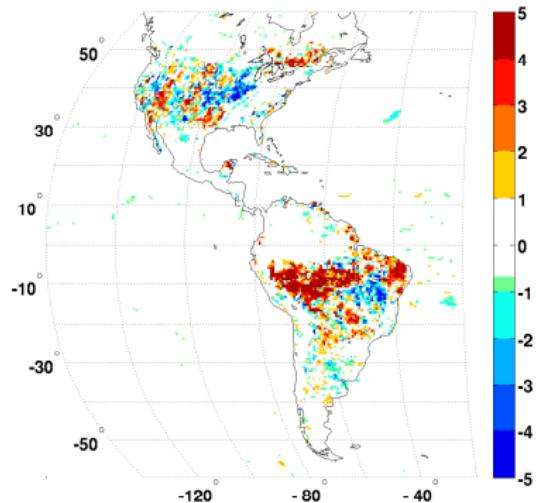
- ▶ Impact seen across domain

LA-DAS minus CNTRL, 20120720H09

TSURF



T2M



- ▶ Impact seen across domain

6. Conclusions

Conclusions 1

- ▶ Recently developed a Land and Atmosphere Data Assimilation System at GMAO, and successfully assimilated geostationary land surface T_{skin} observations into the GEOS-5 AGCM/GSI (to correct short-lived error only)
- ▶ Comparison to other estimates suggests NASA Langley Geostationary T_{skin} observations have good accuracy
 - ▶ Available in near-real time with greater temporal coverage than data from polar orbiters
- ▶ Offline LDAS experiments strongly suggest that assimilation of Geostationary T_{skin} improves the model T_{skin} at the time of the analysis
 - ▶ Improvements limited by very short memory of model T_{skin}
 - ▶ No impact on land surface fluxes/dependent variables

Conclusions 2

- ▶ Coupled LA-DAS experiments shows memory of T_{skin} updates (< 1 day), together with impact on the land surface fluxes and low-level atmosphere
 - ▶ Highlights importance of coupled LA-DAS

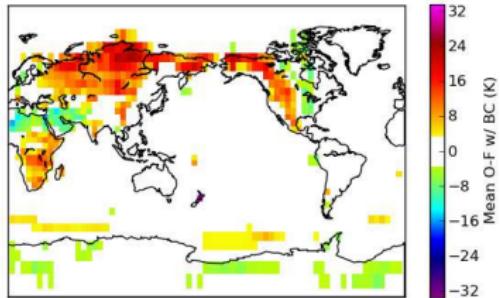
Future plans:

- ▶ Develop an observation bias model for the geostationary T_{skin} observations, then assimilate bias-corrected obs. to correct model T_{skin} biases
 - ▶ With LA-DAS, can link biases in difficult to observe surface variables to atmospheric variables
- ▶ Test impact on broader range of parameters (boundary layer height, precipitation, O-F for surface sensitive atmospheric radiances)
- ▶ Use LA-DAS to assimilate other land surface data sets into GOES-5 (soil moisture/L-band T_B , snow cover, in situ snow depth)

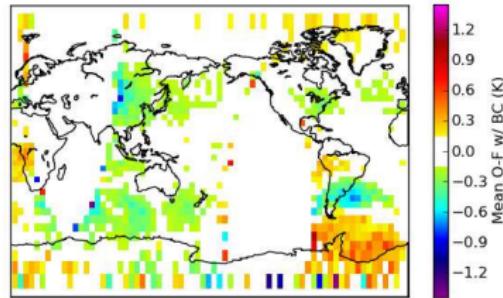
THANK YOU FOR LISTENING.

Mean O-F (K) for 00 UTC, July 2012

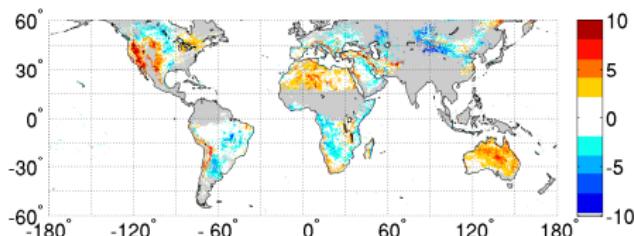
AMSUA-NOAA 18, ch. 1



IASI-METOP, ch. 381

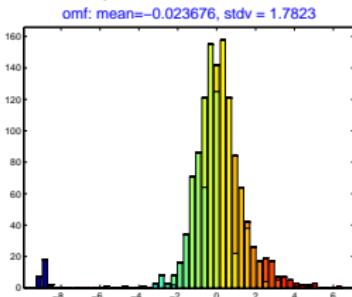


GOES Tskin

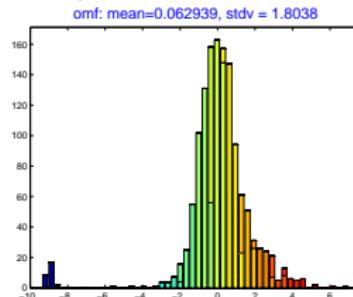


Surface pressure over land, O-F

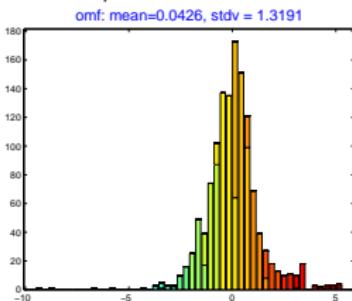
CNTRL, 20120721H00



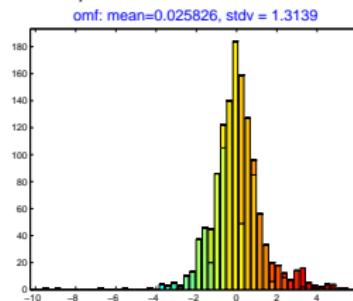
LDAS, 20120721H00



CNTRL, 20120721H12



LDAS, 20120721H12

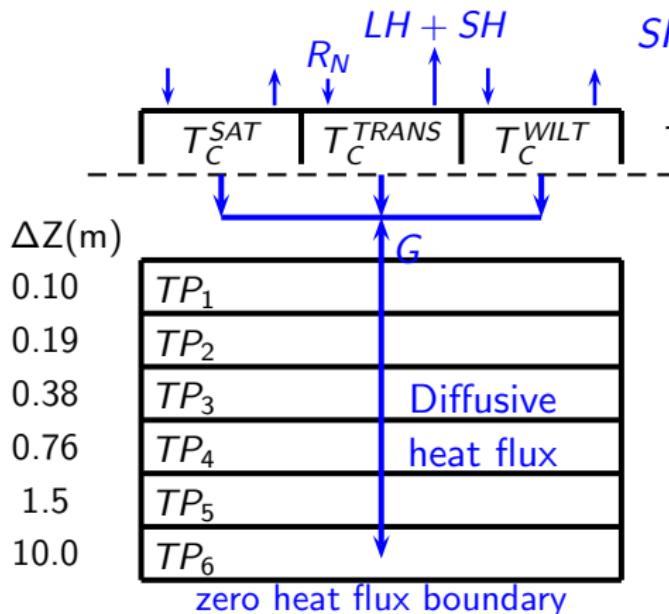


Catchment surface energy states and fluxes

$$\frac{dW}{dt} = R_N - LH - SH - G \quad R_N = (1 - \alpha)R_{S\downarrow} + \epsilon(R_L \downarrow - \sigma_s(T_C^X)^4)$$

$$LH = RESIST_L(e_{sat}(T_C^X) - e_{air})$$

$$SH = RESIST_H(T_C^X - T_{air})$$



$$T_{SURF} = w(T_C^{SAT}, T_C^{TRANS}, T_C^{WILT})$$

$$\Delta(T_C^X) = \frac{\Delta(W^X)}{shc(sfc)}$$

$shc=200 \text{ J/K}$,
or $70,000 \text{ J/K}$ for b-l e'green

$$TP_n = \frac{ghtcnt_n + icehct_n}{shc(rck) + shc(wtr) + shc(ice)}$$

Water assumed 0.5ϕ . If no ice:

$$TP_n = ghtcnt / (2269050 \Delta Z_n)$$